Title of the project

Special Topic Seminar Report

Submitted in partial fulfillment of the requirement of

University of Mumbai

For the Degree of

Master of Engineering
(Electronics & Telecommunication Engineering)

by

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Oct 2015

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Ramrao Adik Institute of Technology
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Certificate

This is to certify that, the special topic seminar entitled

"Visible light Communication and its Applications"

is a bonafide work done by

Student Name
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and is submitted in the partial fulfillment of the requirement for the degree of

Bachelors of Engineering
in
Electronics AND Telecommunication Engineering
to the
University of Mumbai.

Examiner   Supervisor

Project Coordinator   Head of Department   Principal

Acknowledgments

I would like to express my deepest gratitude to my guide, Dr. Mukesh D. Patil, for his excellent guidance caring, patience, and providing me with an excellent atmosphere which helped me in successful completion of this special topic.

I am also thankful to our MiniProject-I Coordinator, Mrs. Ashwini Joshi who devoted their valuable time and helped me in all possible ways towards successful completion of this special topic. I am also grateful to all those who have contributed directly or indirectly to this work.

I am thankful to our Principal Dr. Ramesh Vasappanavara for their support and encouragement.

I would also like to express my deepest thanks to all my friends and my colleagues, who provided a perfect environment for my studies.

Last but not least, I would like to express my heartily gratitudes to my family for their unconditional support and love.

Abstract

Visible light communications (VLC) is a technology for wireless communication using light that can be perceived by the naked eye. VLC uses frequencies other than radio, and they are unrestricted and licence free. The urgent need of VLC is to overcome the problems faced in RF communication. Unlike existing methods of wireless communication, the visible light portion of the electromagnetic frequency spectrum is used in VLC to transmit information. VLC refers to the communication technology which utilizes the visible light source as a signal transmitter, the air as a transmission medium, and the appropriate photodiode as a signal receiving component. This report provides an overview of applications and design challenges for VLC, compare it with other existing communication technologies and presents the modulation techniques used.

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Chapter 1

Introduction

Now a days, wireless communications has become necessary to our lives and we transmit a lot of data every day. The main way we transmit wireless data is by using electromagnetic waves, in particular radio waves. However, radio waves can support only limited bandwidth because of restricted spectrum availability and interference. Furthermore, radio spectrum is full to bursting and it is difficult to find radio capacity to support media applications [3].

There is an emerging wireless communication technology with a promising future and which can be a complement of radio waves: Visible Light Communication (VLC). VLC uses the visible light portion of the electromagnetic spectrum to transmit information. This emerging technology offers optical wireless communications by using visible light. The visible spectrum is 10000 times larger than that of radio spectrum. The premise behind VLC is that because light is present everywhere now a days, communications can ride along for nearly free.

VLC is basically a short range optical wireless communication technology that uses a visible light source as a signal transmitter, the air as a transmission medium or channel and a signal receiving device. Generally, the transmitters are Light Emitting Diodes (LEDs) while the principal device of the receiver is a photodetector, usually a photodiode. By using VLC in short distance applications, we can supplement radio waves achieving high data rates and a larger bandwidth [1].

Light is part of the electromagnetic spectrum, specifically the visible light spectrum, which covers wavelengths between 380 nm-780 nm. We have already a lot of LED-based lights installed in the world and we can use them for communications. A LED is a semiconductor device that has the advantages of fast switching, power efficiency and emits visible light that is safe for the human because it is not harmful to vision. Therefore, we can both illuminate and transmit data everywhere [1].

Recently, LED research has focused on the emerging lighting infrastructure due to Green IT technical innovations. LED lighting is superior to existing incandescent and fluorescent lighting in terms of the long life expectancy, high tolerance to humidity, minimal heat generation, and low power consumption. Another important benefit of LEDs is that it is a controllable digital device. Therefore, many attempts have been made to merge LEDs with information technology (IT). Among them, visible light communication (VLC), which uses LED as a communicating device, has emerged as a new Green IT convergence technology.

We can see the VLC environment in the Figure 1.1. All devices such as TV, fridge, PC etc. are wirelessly connected to the network. After the deployment of 3G systems, researchers have observed that human needs are moving towards more and more bandwidth hungry applications. In order to fulfil the needs, fourth generation (4G) and beyond systems are being introduced realizing the fact that heterogeneous access techniques must be available. Now the race is not to connect every human with internet but everything will be wirelessly connected to the network.

Figure 1.1: VLC Environment [19].

1.1 Visible light communication

1.1.1 Brief history of Visible Light Communication.

The use of light to send messages is a very old idea. Fire and smoke signalling were used in ancient civilizations. For example, the ancient Greeks used polished shields to reflect sunlight to signal in the battle and Roman records indicate that polished metal plates were used as mirrors to reflect sunlight for long distance signalling. Chinese started using fire beacons followed by the Romans and American Indians using smoke signals.

In the early 1800s, the US military used a wireless solar telegraph called Heliograph which is shown in figure that signals using Morse code flashes of sunlight reflected by a mirror. The flashes are produced by momentarily pivoting the mirror, or by interrupting the beam with a shutter. The diagram of heliograph is shown in Figure 1.2. The navy often uses blinking lights, i.e. Aldis lamps, to send messages also using Morse code from one ship to another.

Figure 1.2: Heliograph [17].

In 1880, the first example of VLC technology was demonstrated by Alexander Graham Bell with his photophone that used sunlight reflected off a vibrating mirror and a selenium photo cell to send voice on a light beam. The transmitter and receiver of photophone is shown in Figure 1.3.

Figure 1.3: (a) Photophone transmitter. (b) Photophone receiver and handset [17].

Until the late 1960s, radio and radar communications were more successful than optical communications (OC). OC started to get real attention with the invention of the light amplification by stimulated emission of radiation (laser) and the laser diode (LD) in the 1960s, followed in the 1970s by the development of lowloss optical fibres (OFs) as a medium for transmitting information using light, the invention of the OF amplifier in the 1980s, and the invention of the in-fibre Bragg grating in the 1990s. These inventions formed the basis for the telecommunications revolution of the late 20th century and provided the infrastructure for the Internet. The Nobel Prize in physics 2009 went to three scientists (Charles K. Kao, Willard S. Boyle, George E. Smith) who have played important roles in shaping the modern information technology due to their ground breaking achievements concerning the transmission of light in fibers for optical communication. Advancements in basic opto-electronic devices, such as LEDs (light emitting diodes) and LDs, p-intrinsic-n (PIN) photodiodes (PDs) and avalanche photo-diodes (APDs) and various optical components have attracted engineers to consider optical sources for wireless data transmission which has led to modern optical wireless communications (OWC) [17].

The first indoor OWC system was developed over 25 years ago. In 1979, an indoor OWC system was presented by Gfeller and Bapst. In their system, diffuse optical radiation in the near-IR region was utilised to interconnect a cluster of terminals located in a room to a common cluster controller. During the last ten years, we have witnessed the emergence of visible light communications (VLC) fuelled by solid-state lighting (SSL) technology. SSL is a rapidly developing area, both in terms of commercial exploitation, and academic and industrial research. LEDs with a wide range of colours are available, including white light. The output power as well as device efficiencies are increasing rapidly. The field of applications is also expanding. White LEDs are commonly used as replacements for incandescent lamps due to more than 10 times improved energy efficiency. Therefore, LED lighting is set to revolutionise the way we illuminate our homes, offices, public buildings and streets.

These SSL sources, being semiconductor devices, come with an additional feature. Their light intensity can be varied at very high speeds, and so their functionality can be extended by means of intensity modulation (IM) to also become a wireless communication device.

VLC originated in Japan and the visible light communications consortium (VLCC) was established in November 2003. The VLCC has major companies in Japan on board and aims at publicising and standardising VLC technology. The formation of the VLCC has stimulated worldwide interest in VLC technology, and the first IEEE standard for VLC - IEEE 802.15.7 has emerged recently. University of Edinburgh academics have worked on VLC since 2004 and have developed enhanced modulation schemes that enable high data rates to be achieved using standard LED light bulbs.

1.1.2 Spectrum Analysis

Since Visible light communication is a data communication technology that uses visible light between 380 nm and 780 nm. These wavelengths correspond to a frequency range of approximately 384 THz to 789 THz. In Figure **??** and 1.1, we can see a diagram of the visible light spectrum. The visible light spectrum is 10000 times larger than that of radio spectrum.

1.1.3 Characteristics of VLC

The main characteristics of this technology are summarized below [1]:

- Bandwidth : The bandwidth is virtually not limited, it offers a frequency band of approximately 400THz.
- Efficiency : VLC is highly energy efficient since illumination and transmission of data are done at the same time.
- Data Rates : VLC can achieve high data rates (hundreds of Mb/s) and it can therefore be used for high speed wireless communications.
- Cost : As VLC uses the visible light spectrum it is free of cost. Furthermore, transmitters and receivers are cheap.
- Human Safety : VLC is harmless to human health and it is not injurious to the human eye.
- Omnipresent Nature : We have the infrastructure because there are already a lot of LED-based lights installed in the world which are potential VLC transmitters and therefore we can use them for communications.
- Security : As light waves do not penetrate opaque objects they can not be intercepted, so it offers a very secure communication. It is very difficult for an intruder to make use of your signal.
- Visibility : It is great to see data being communicated by a beam of light. What you see is what you send!

1.2 Comparison With Other Commuication Technologies

1.2.1 Comparison with IR communication

The differences between VLC and infrared communication are listed in Table 1.

The infrared communication is standardized by the IrDA (Infrared Data Association) and the IrDA is still developing advanced application of infrared communication. The data rate for infrared communication (Knutson, 2004) includes 4 Mb/s (FIR), 16 Mb/s (VFIR), and etc. On the other hand, the VLC data rate is dependent on the LEDs modulation bandwidth and the standardization on physical layer specifications has not yet been published. Some of researches have reached around 20 Mb/s. Since the resonant-cavity LEDs shows the modulation bandwidth $>$ 100 Mb/s, it is expected that the VLC system with $>$ 100 Mb/s data rate is possible by using the high-speed LEDs and appropriate multiplexing techniques.

The transmission distance for VLC is possible up to several meters due to its illumination requirement. Since the infrared communication is used for a remote controller, the maximum distance is 3 meters. The VLC transmitter emits multiple-wavelength light from red to violet and the exact analysis will become more complex than infrared communication.

Table 1.1: Comparison of short-range wireless communication technologies. (FIR: fast infrared, VFIR: very fast infrared) [15].

Parameters	Visible Light Communication	Infrared Communication
Data Rate	>100Mb/s possible (LED dependent)	4Mb/s(FIR),16 Mb/s (VFIR)
Status	Research and standardization in IEEE	Standardization (IrDA)
Distance	meters	3 meters
Regulation	No	No
Security	Good	Good
Carrier wavelength (frequency)	380 780 nm visible light (multiple wavelengths)	850 nm infrared
Services	Communication, illumination	Communication
Noise Source	Sun light, Other illumination	Ambient light
Environmental	Daily usage Eye safe (visible)	Eye safe for low power (invisible)
Applications	Indoor vehicular communication, Optical ID	Remote control, Point to point connection

Due to the wavelength of the light source, the noise sources will be different. For infrared communication, noise comes from ambient light containing infrared light. In the case of VLC, the sunlight and other illumination light can be noise sources. Also, the visible light is in our daily lives and we can detect it with human eye. Therefore, the VLC is eye safe.

1.2.2 Comparison with Radio Waves

Although radiofrequency communications is the most popular technology today, it also has disadvantages. VLC is compared with radiofrequency using five main concepts.

- Capacity : Radio spectrum is full and it is difficult to find radio capacity to support the demand of wireless data transmissions for media applications. The radio waves are limited, expensive and there is only a certain range of it. By using VLC more spectrums will be available and due to the infrastructure of LED-based lights installed in the world there is a potential for VLC as transmitters.
- Efficiency : Radio waves consume a lot of energy while VLC is highly energy efficient since illumination and transmission of data are done at the same time.
- Cost : VLC transmitters and receivers devices are cheap, there is no need for using expensive RF units.
- Safety : Radio wave creates Electromagnetic Interference (EMI), known to interfere with airplanes instruments and equipment in hospitals, and is potentially dangerous

in hazardous operations, such as power/nuclear generation or oil and gas drilling. On the other hand, VLC uses light instead of radio waves, which is intrinsically safe and does not create EMI. Hence, this technology can be used in many places.

- Security : Radio waves penetrate through walls and they can be intercepted. By using VLC data is transmitted where the light is because light does not penetrate through walls, that is to say, VLC provide a secure data communication.
- Human Health : The transmission power of radio waves van cannot be increased over a certain level because there are serious health risks for humans. VLC is an attractive candidate in a consumer communication system.

This report is organized as follows:

Chapter 1 includes about visible light communication history, spectrum analysis for VLC, characteristics of VLC along with comparison between VLC and other technologies. Chapter 2 includes working technology of VLC. Chapter 3 provides an explanation for the transmitter, channel and receiver required for VLC. Chapter 4 focuses on challenges for VLC. Chapter 5 is about modulation technique which are used in VLC and about standarisation for VLC. Chapter 6 includes various applications of VLC. Chapter 7 ends with an conclusion.

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